Chapter 6

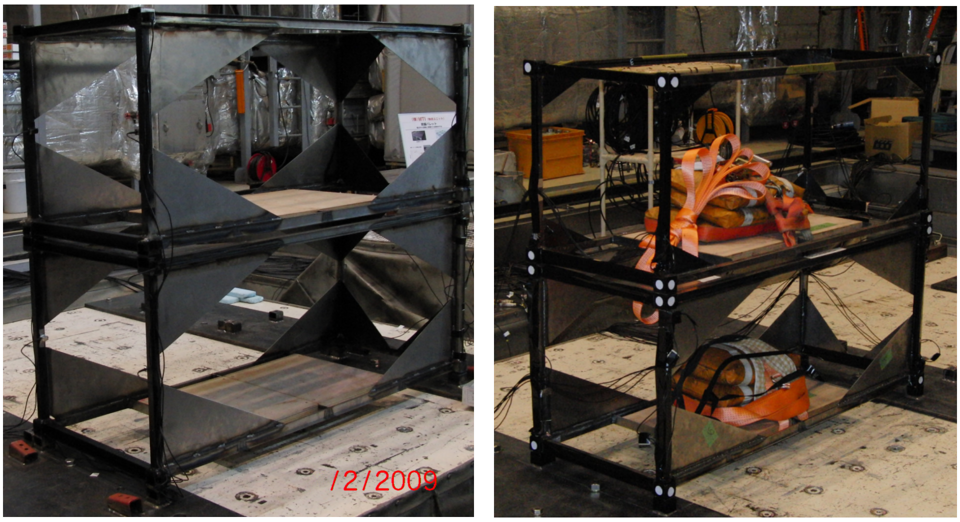
Pilot Study

6.1 Objectives and Significance

Following what was mentioned by van Teijlingen *et al.*, before testing the scaled models in realistic conditions, a pilot study was conducted to assess:

- Adequacy of the instruments and their operations,
- Checking the design of the research protocol,
- Assessing whether the research protocol is realistic and workable,
- Establishing whether the sampling frame and technique are effective,
- Identifying logistical problems which might occur using proposed methods,
- Estimating variability in outcomes to help sample size determination,
- Collecting preliminary data,
- Assessing the proposed data analysis techniques to uncover potential problems.

This part of the dissertation describes a pilot study employing experimental and numerical analysis of a two-tier, scaled containers and twist locks under controlled vibrational parameters, e.g., frequency and amplitude of driving excitation. The experiment was designed to validate the numerical model employing an experimental technique described in section 6.2.3. Furthermore, a numerical analysis consisted of a well established numerical method: finite element analysis that it will be described in section 6.2.4.



(a) Non loaded experimental setup. (b) Loaded experimental setup.

Figure 6.1: The two setups used for experimentation (2x1).

6.2 Research Design (2x1)

6.2.1 Objects of Study (2x1)

Two scaled models, built based on Froude scaling laws (see chapter 3), were used to perform dynamic tests with controlled driving excitation. The objects of study that represent the system studied are depicted in Figures 6.1 and 6.2.

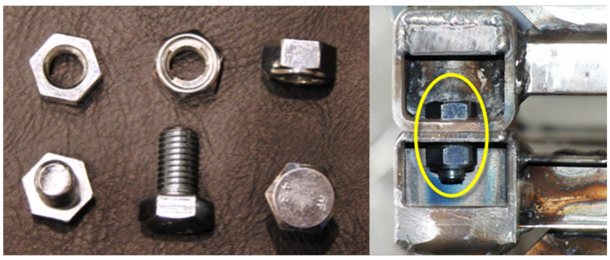


Figure 6.2: Detail of the bolts used to emulate twistlock (left), and disposition of the bolts in the system (right).

6.2.2 Driving Excitation and Physical Parameters (2x1)

A sinusoidal function was used as driving excitation of the system. Two variables belonging to it were chosen to provide control over the trials: frequency and amplitude. A list of the driving excitation parameters used for every trial is presented in table 6.1. Moreover,

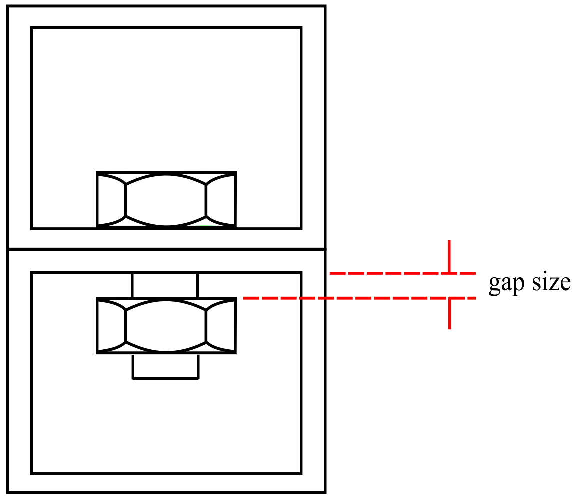
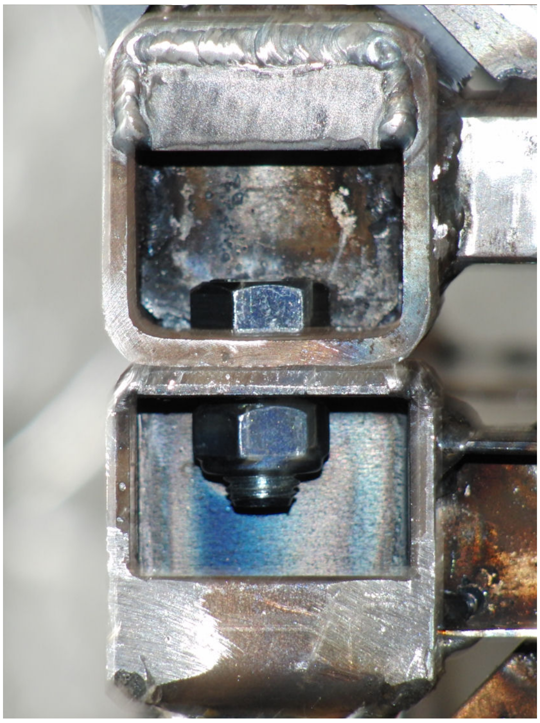


Figure 6.3: Schematic representation of the gap used as a variable.

two physical variables were idealized to provide extra information about the system: dead weight (payload) added to the system and twistlock gap size. For the first variable, trials were divided into loaded (Figure 6.1a) and unloaded (Figure 6.1b) cases. For the loaded cases, and extra mass of 75 kg was added to each scaled model. For the second variable, gap size in the twist lock was adjusted with 1 and 2 mm for every trial. Please refer to Figure 6.3 for better understanding.

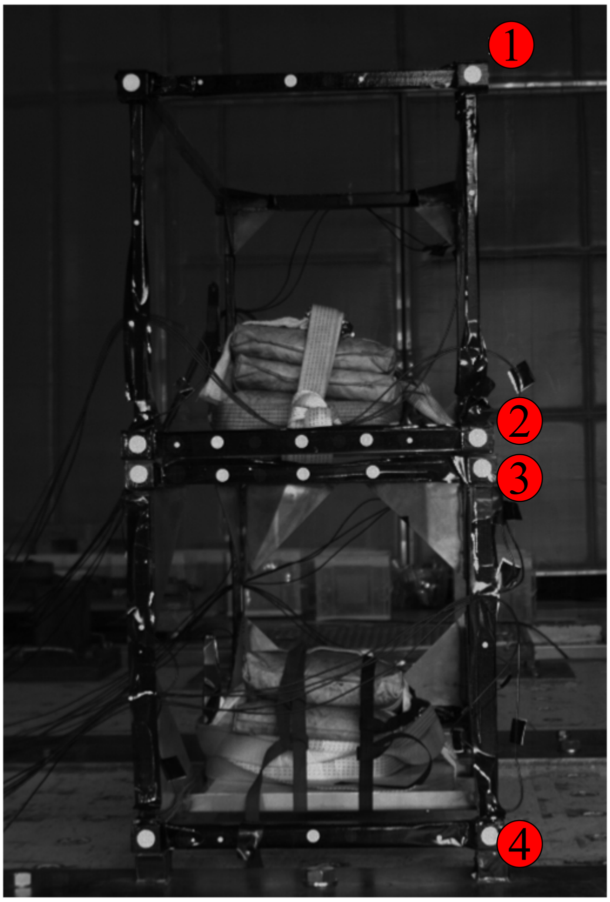
6.2.3 Experimental Investigation and Apparatus (2x1)

The two scaled models were fixed to a shaking table through its corner castings using bolts as twist locks, emulating the same conditions faced in regular securing process administrated before container transportation. Please refer to Figure 6.4 for details of this connection. The shaking table was excited according to the conditions explained in table 6.1, where all trials were recorded for 8 seconds. Eight reflexive markers positioned on the corner castings of each scaled model, corresponding to their open side, were used to record displacement using a high speed camera (model NVC–SL, PHOTRON, USA, Inc.) with a sampling rate of 500 Hz. Numbering of the reflexive markers follow the schematics showed in Figure 6.4c. An experimental apparatus is described in sections 2.2.1 and 2.2.2. Data recorded are filtered using a low pass filter (Hamming window). Cut-off frequency used for filtering was defined based on an residual analysis as defined in section 2.6.



(a) Connection between corner castings.

(b) Sockets were welded to the shaking table.



(c) Numbering of the reflexive markers.

Figure 6.4: Details of the linking components and labeling (2x1).

Table 6.1: Experimental conditions used to control the driving excitation for the pilot experiments

Frequency [Hz]	Amplitude [mm]				
5	1	2	5	10	15
10	1	2	4	6	8
15	1	2			
20	1	2			

6.2.4 Numerical Investigation: Finite Element Analysis (2x1)

A simplified 3-D finite element model of the system: two scaled models of a 20 ft ISO freight dry container, twist locks and shaking table was developed using a commercial software (Abaqus version 6.7, Dassault Systems). Details of the model's structure are presented in section 5.1. Numerical model is depicted in Figure 6.5. Moreover, twist locks were modeled using the mathematical relationship depicted in Figure 5.7. Finally, the shaking table was considered a rigid body where the driving excitation follows same conditions imposed in experiments (see table 6.1). To provide damping, discrete damping elements (dashpots) were implemented to the 3-D model in the same line of action of the non-linear springs. Numerical analysis accounted for geometry non-linearity considering a dynamic study in an implicit integration scheme.

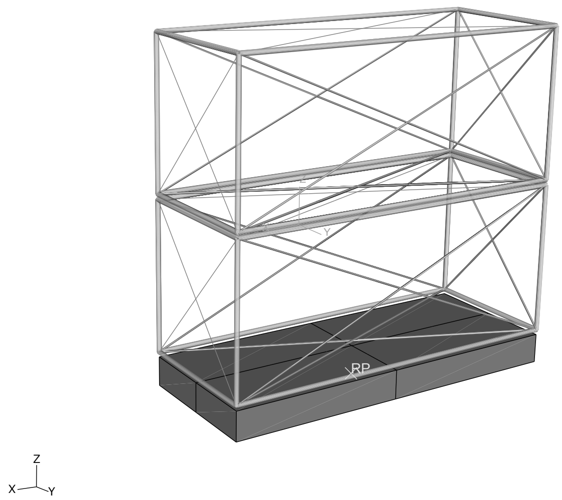


Figure 6.5: Finite element model of the two-tier single stack case (2x1).

6.3 Results and Discussion (2x1)

Because driving excitation was strictly vertical, displacement in the lateral direction was neglected, i.e., results corresponding to lateral motion were not considered for means of comparison between experimental and numerical data. For means of comparison, only displacement of point 1 was considered for every case. The choice of this point is based on the fact that this position will experience the highest values of radial forces. Thus, this region is expected to present the maximum response amplitude inflicted on the structure. This section will discuss the effects of each parameter (see section 6.2.2) separately using, when appropriate, comparison of RMS values and time history comparison. The values used for comparison and respective relative error based on the experimental data are presented in table 6.2.

6.3.1 Amplitude (2x1)

The first set of analyses examined the effect of driving frequency amplitude on the displacement of point 1 using time history and RMS values comparison. From the first type of comparison, it is easy to identify that a positive correlation was found between amplitude of driving excitation and amplitude of response,i.e., they are directly proportional, as can be seen in Figures 6.6 and 6.7. Thus, from this perspective, i.e. can be said that numerical and experimental data have a good level of agreement. However, this kind of comparison is too simple, and does not lead to inference about the nature of the system. In this panorama, a better option is to plot a graph depicting the relation between the driving excitation amplitude versus the ratio between driving excitation amplitude and response amplitude. Such comparison is depicted in Figures 6.8 and 6.9. From this approach some inferences can be drawn.

Analysis of Figures 6.8a, 6.8b, 6.9a and 6.9b, reveals that the system converges to non-linear behavior with increase in driving excitation amplitude. The study presented enough body of evidence to support the idea that the system responds linearly to small amplitudes (as can be seen in the Figures 6.9a and 6.9b, but there is a period of transition where the system becomes unstable and presents non-linear behavior with amplitudes higher than 10 mm (depicted in Figures 6.8a, and 6.8b). Although this phenomena is pronounced and easily identifiable in the cases without load, the same is not so clear in loaded cases. We believe that differences in construction for the numerical model are responsible for such disparities. Experiments involving loads had sand bags fixed to each container floor using cargo belts, while their simulation counterparts, payload was added to geometrical center. Consequently, both configurations will induce a complete different distribution of moments over the system, increasing differences between experimental and numerical

Table 6.2: Experimental and numerical results for the cases studied (2x1)

Case			Amplitude (RMS)[mm]		Relative error[%]
Frequency[Hz]	Amplitude[mm]	Load	Experimental	Numerical	
5	2	n	1.48	1.52	2.41
5	5	n	3.72	3.80	2.10
5	10	n	7.70	7.61	1.16
5	15	n	10.71	11.37	6.18
5	2	y	1.59	1.41	11.59
5	5	y	3.86	3.32	13.88
5	10	y	7.93	8.03	1.32
5	15	y	10.48	11.77	12.32
10	1	n	0.79	0.83	5.46
10	2	n	1.38	1.93	8.83
10	4	n	3.29	2.93	0.91
10	1	y	0.88	0.84	4.94
10	2	y	2.07	2.13	2.96
10	4	y	3.84	3.86	0.42
15	2	n	1.60	1.52	5.14
15	2	y	0.75	np	np
20	1	n	2.18	np	np
20	2	y	1.98	2.01	1.72
20	2	n	1.39	np	np

results. Moreover, it seems that frequency plays a role in such differences as well. For instance, for 5 Hz cases, relative error was higher for the loaded cases when compared to not loaded cases. In the other hand, for 10 Hz cases, the opposite was observed. Authors do not have a plausible explanation for such behavior.

6.3.2 Frequency (2x1)

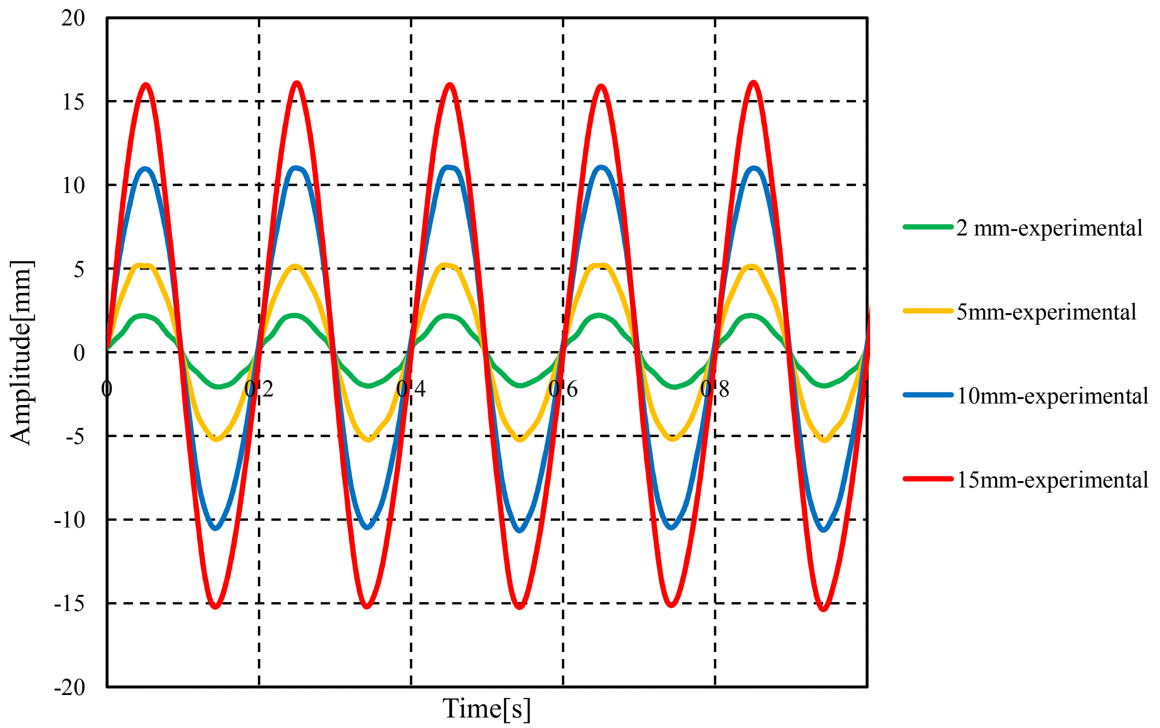
Analyzing response of the system as a function of frequency is essential to understand and identify important phenomena in a system, e.g., resonance. However, in this kind of approach, the experiments must include a wide range of frequencies. The study included four frequencies, a number not big enough to make possible a plot of the frequency-response function. The plot represented in Figure 6.10 as a frequency-response function has a very limited range, which is not enough to infer anything about how the system behaves. However, some interesting findings emerged from analysis of the time history. The results, as shown in Figure 6.11, indicate that the system becomes non-linear with frequencies about 15 Hz. The first trials, with frequencies of 5 and 10 Hz, as can be seen in Figures 6.8a and 6.9a, presents linear response, with exception of the cases where amplitude have high values. Time history of the 15 Hz case, as can be seen in Figure 6.11, points out clearly this non-linearity. This non-linearity was accentuated in the case where extra payload was added to the system, as depicted in Figure 6.11b. For such case, analysis in frequency domain shows the appearance of another frequency (22.5 Hz) compounding the response (See Figure 6.12). Authors attribute this non-linearity to the gap.

6.3.3 Payload (2x1)

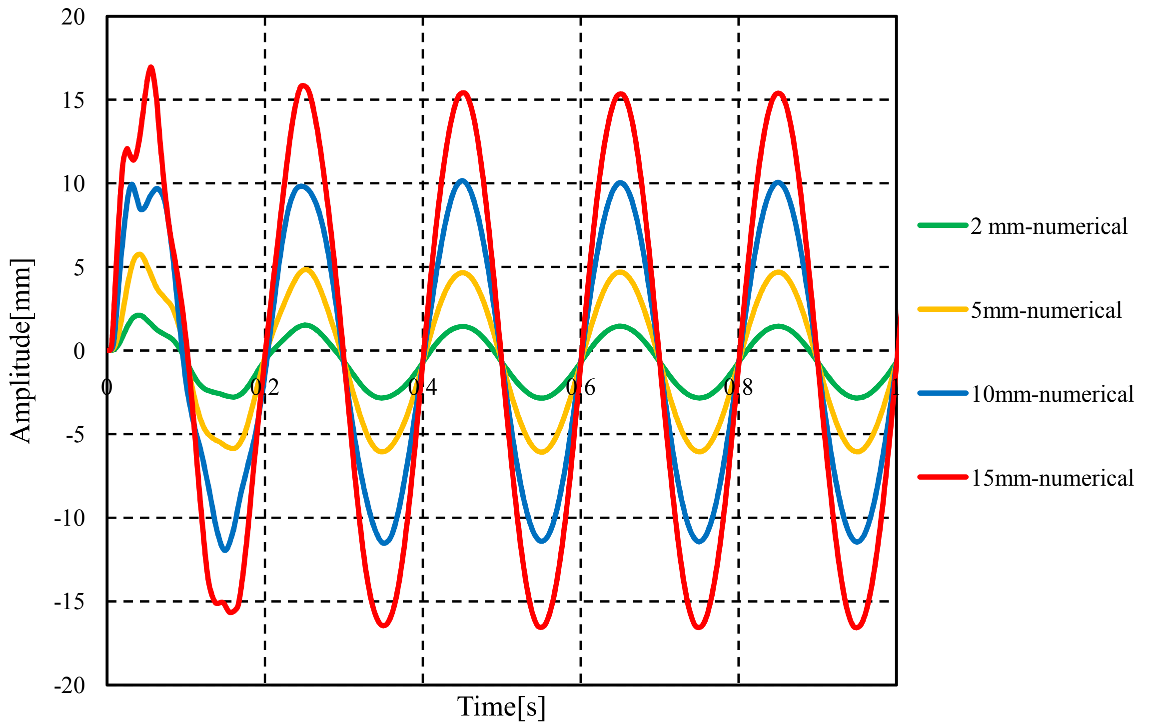
The system responses distinctly depending on the inclusion of a dead weight (payload). For frequencies of 5 and 10 Hz, for most cases, loaded cases have higher amplitudes for the negative part of the cycle, what may be caused by inertia caused by gravity acting on the extra load (see Figure 6.14). Notably, 15 Hz cases have opposite behavior. However in this case, non-linearities play the most prominent role in the response (see Figure 6.14a).

6.3.4 Gap size (2x1)

Regarding the mechanical behavior of the system, gap proves to be the highest source of the non-linearity, as can be seen in Figure 6.14b. Its effect in the system linearity is more acute than frequency effect.This is the most important finding to emerge from this study and it will be a point to be explored in the next chapters and any further study.

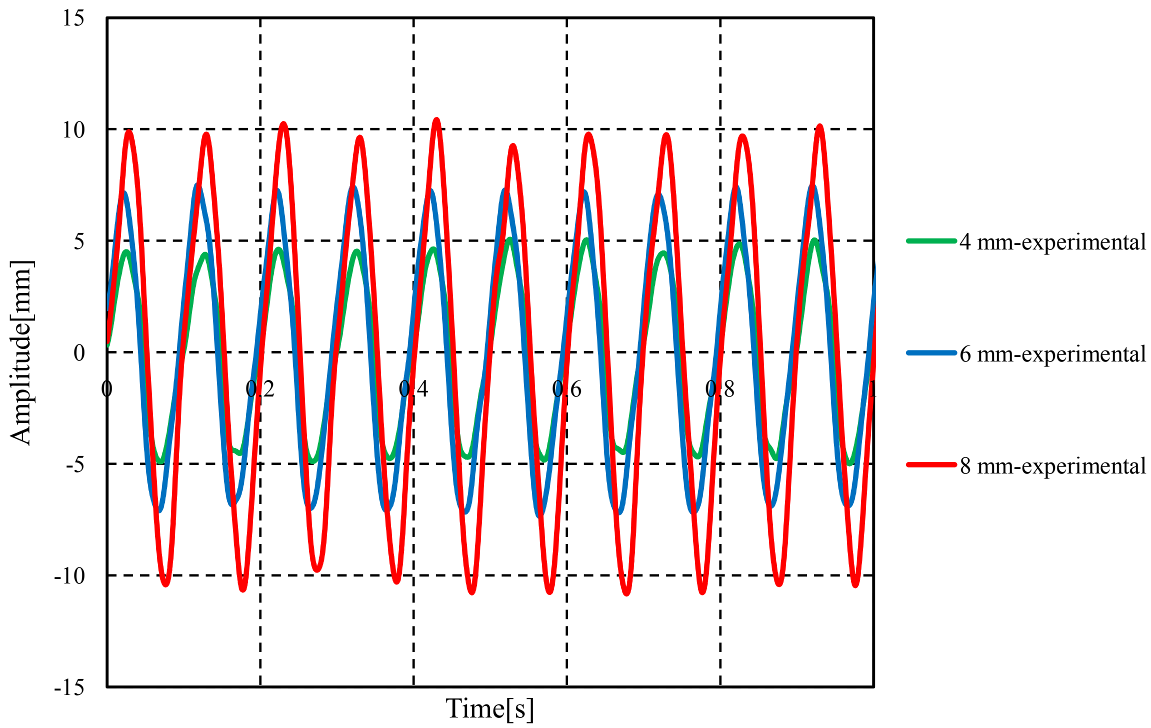


(a) Experimental results.

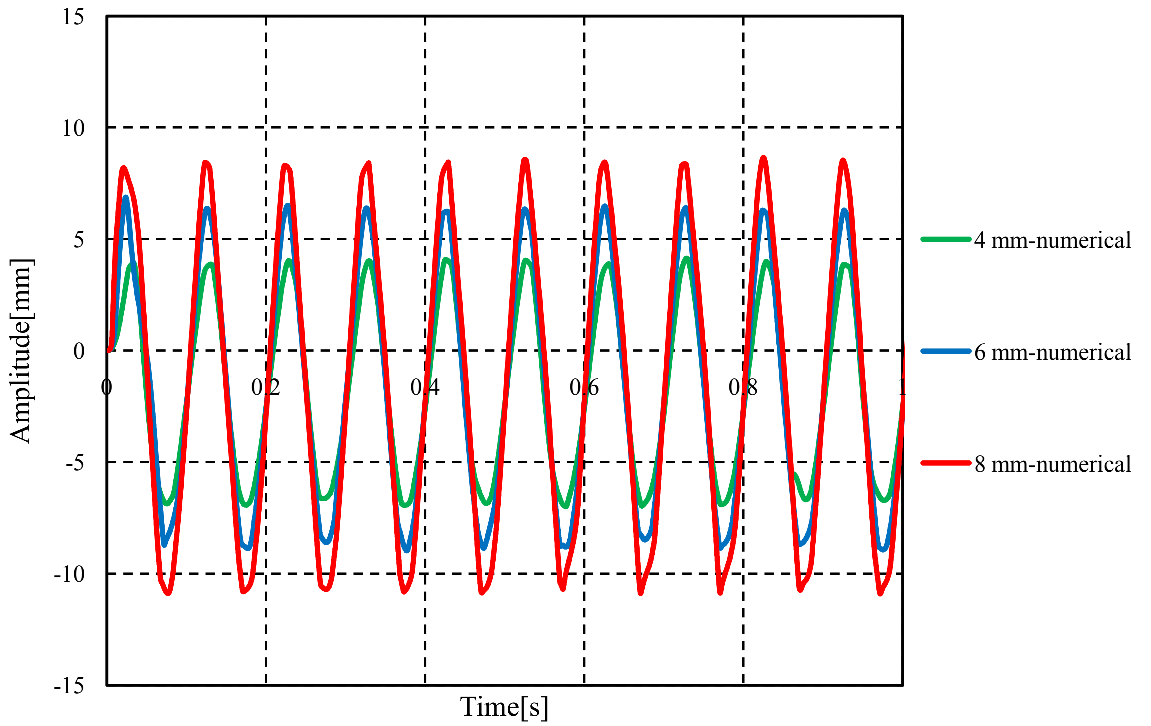


(b) Numerical results.

Figure 6.6: Amplitude of response for point 1 (2x1–5Hz–non loaded).

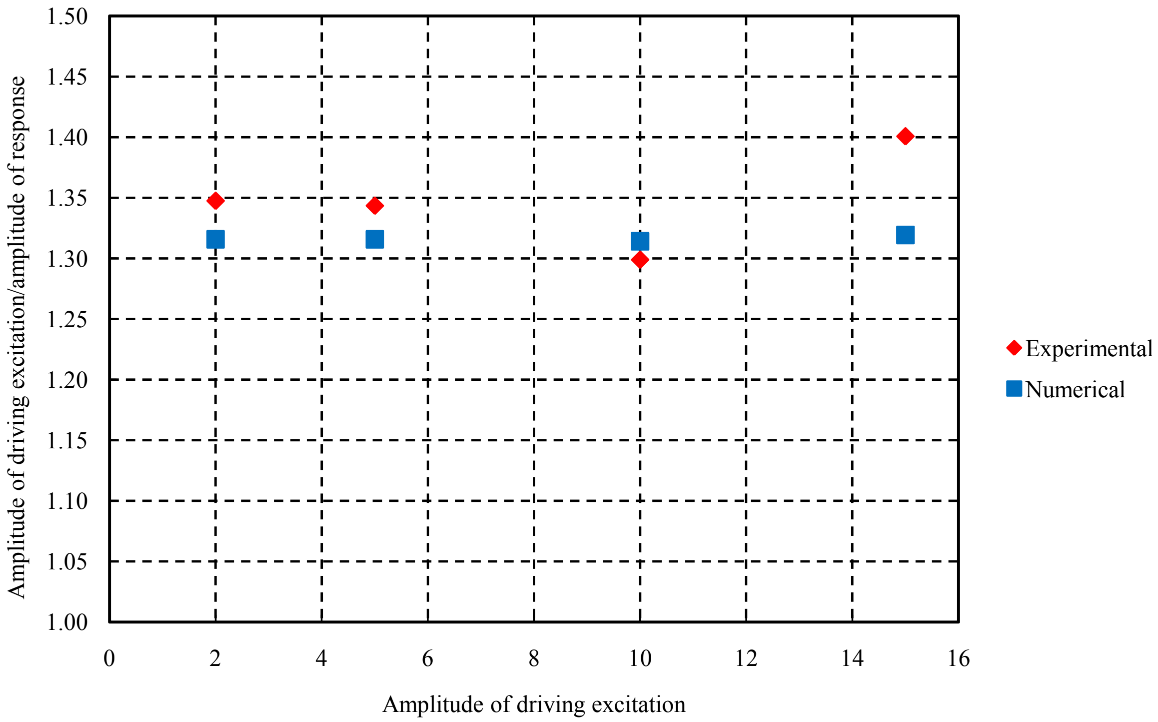


(a) Experimental results.

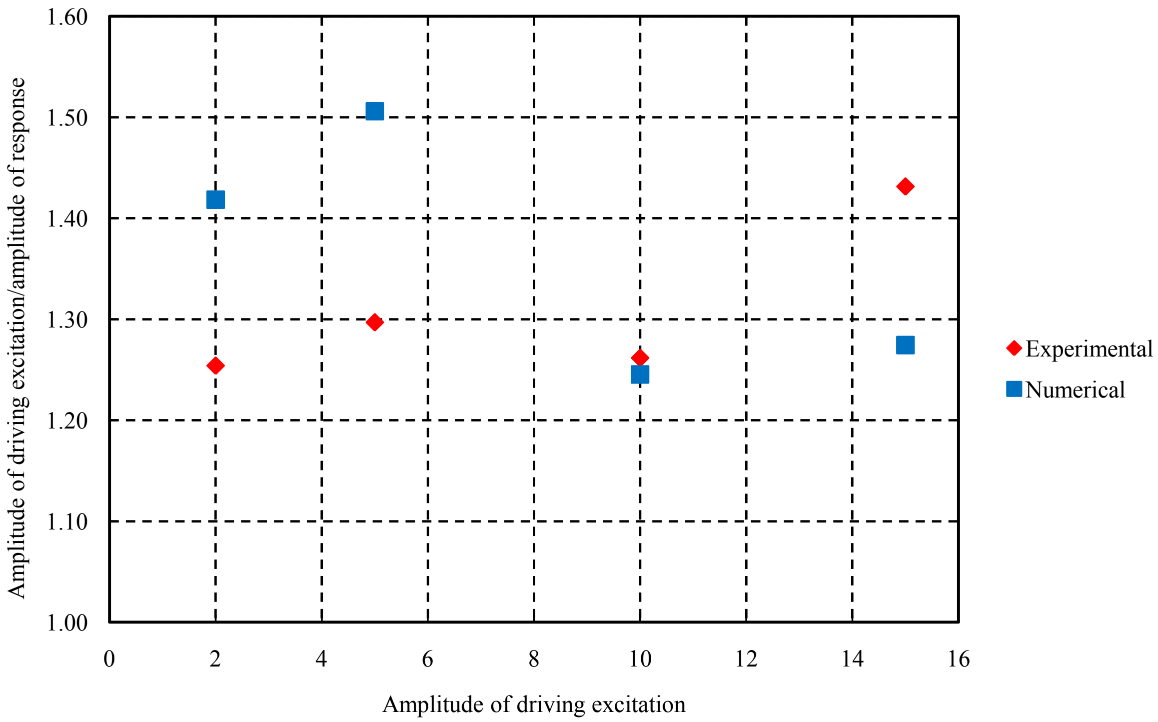


(b) Numerical results.

Figure 6.7: Amplitude of response for point 1 (2x1–10Hz–non loaded).

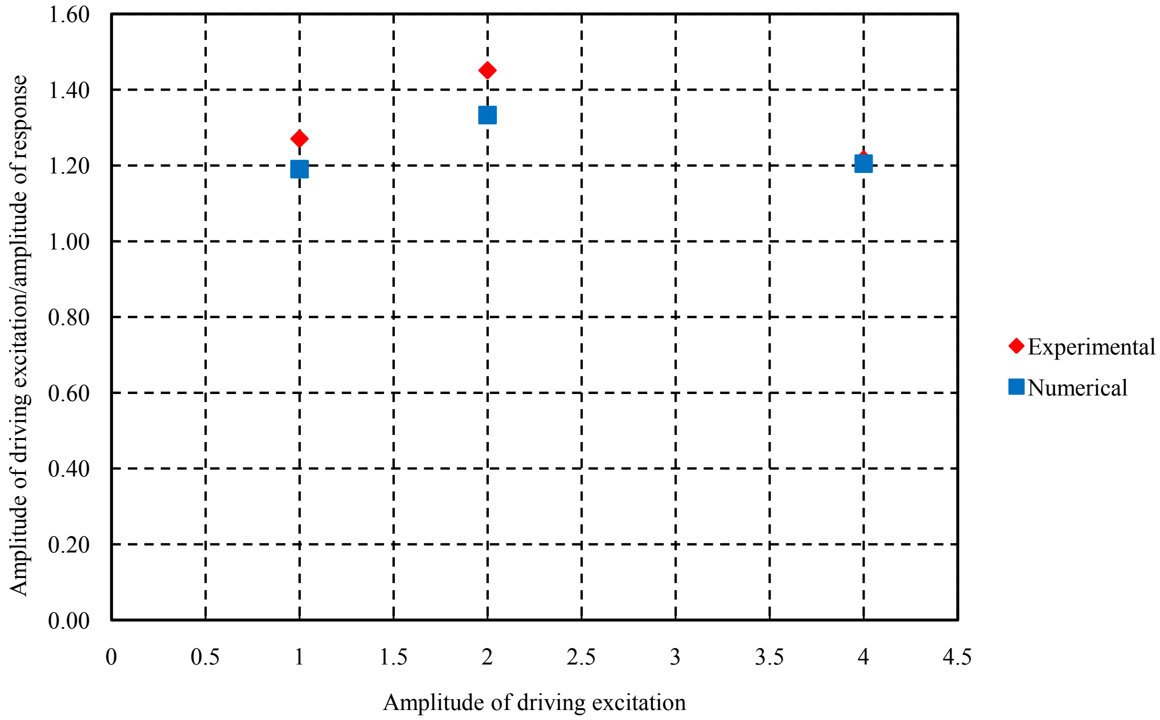


(a) Non loaded case results.

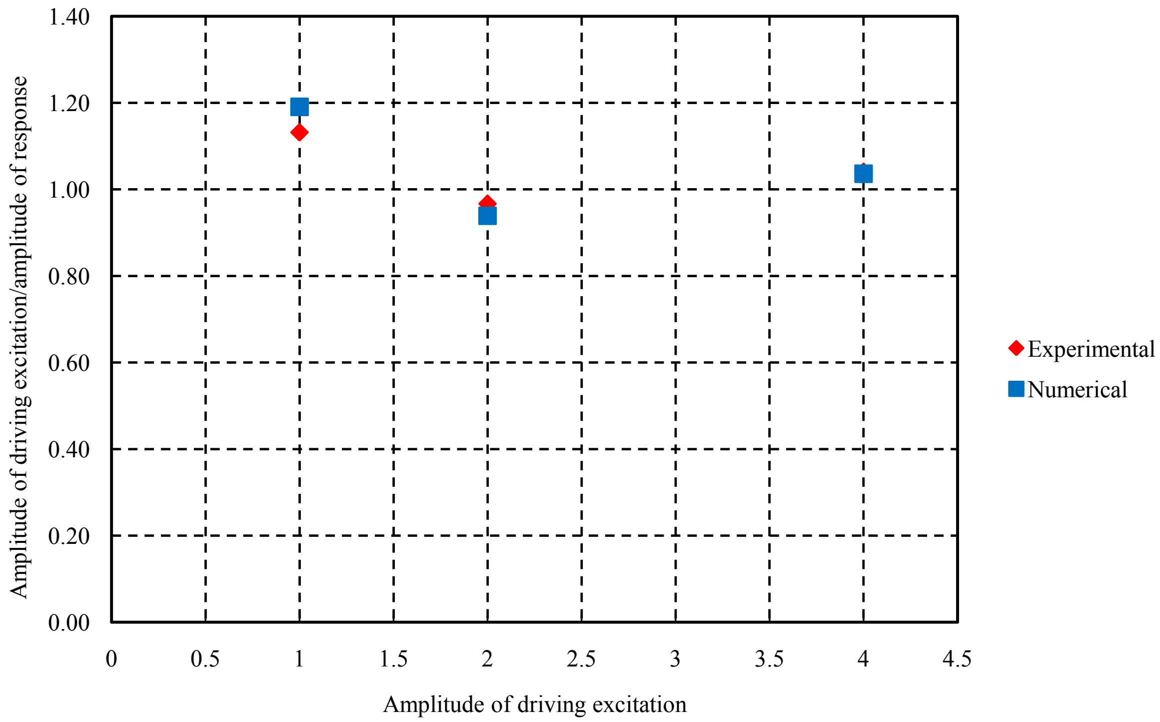


(b) Loaded case results.

Figure 6.8: Response comparison of RMS value for point 1 (2x1–5 Hz).



(a) Non loaded case results.



(b) Loaded case results.

Figure 6.9: Response comparison of RMS value for point 1 (2x1–10 Hz).

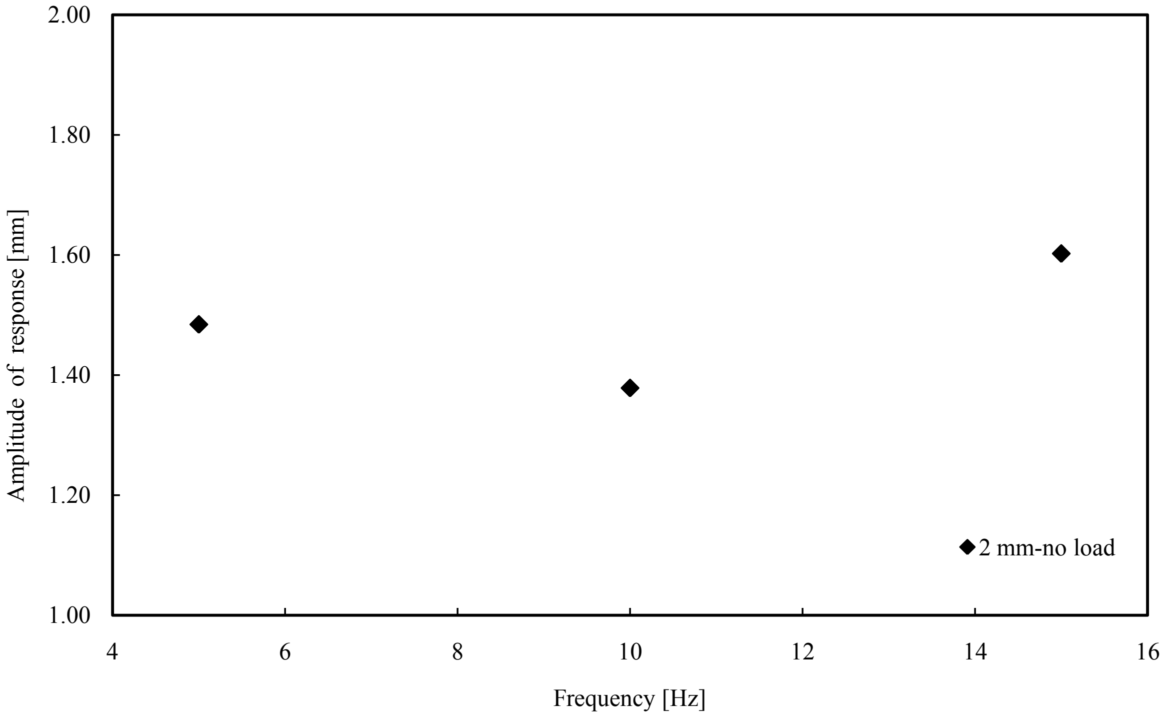


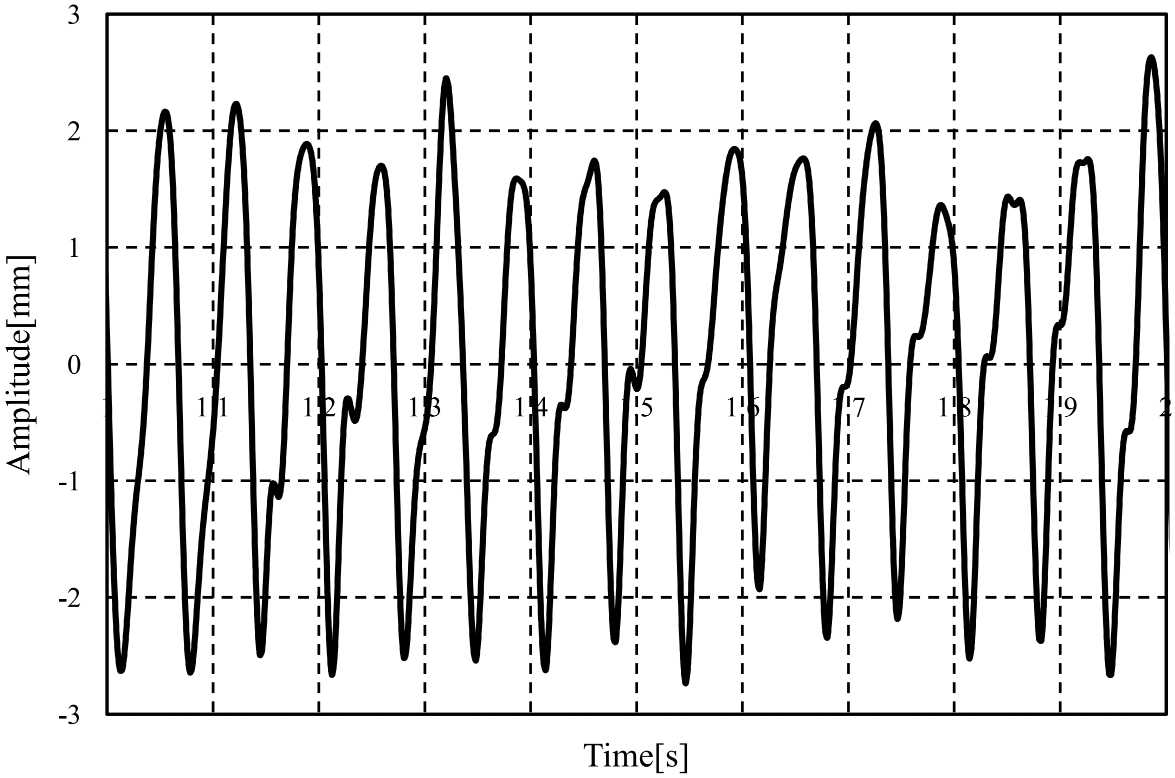
Figure 6.10: Frequency-response function for the experimental data (2x1).

6.4 Final Considerations about the Pilot Study

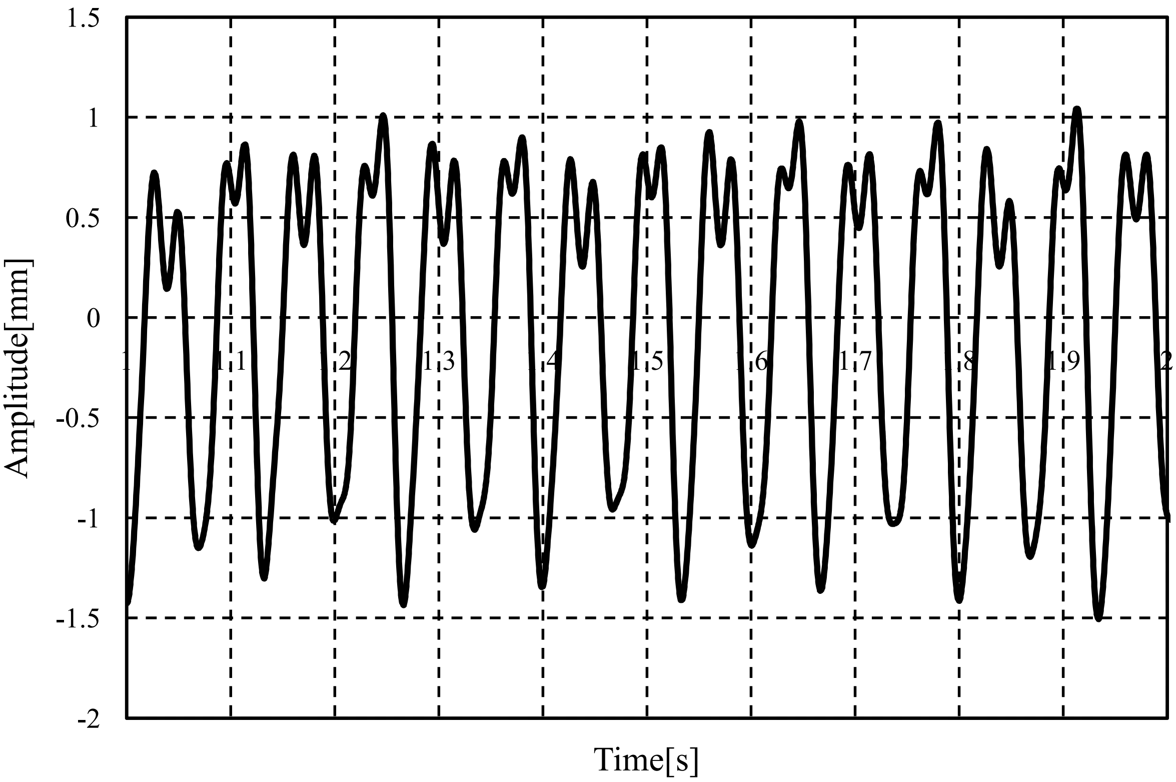
The most important limitation lies in the fact that only a limited number of cases were investigated. Thus, the necessity of widening the study is evident. However, the purpose of this project was to investigate the adequacy of the research design in providing answers about the fundamental mechanical behavior of a container stack, i.e., to establish whether the parameters and techniques employed were appropriate to understand container stack dynamics. From this pilot study some conclusions can be inferred:

- Amplitude of the driving excitation is an important parameter that must be used as control variable in further studies. As expected, the system response presents an easily identifiable influence from this variable that should be explored in distinct driving excitations, e.g., yawing, pitching, etc.

- Following the example of the amplitude, frequency must be employed as a control variable. However, frequency values must be bounded in a low rage. This is consequence of the fact that most important phenomena were observed in low frequencies. Physically, a container ship's motions, even when facing extreme conditions, present very low frequencies, so the study of frequencies above 5 Hz is not



(a) Case: 2 mm–15 Hz–1 mm gap–non loaded.



(b) Case: 2 mm–15 Hz–1 mm gap–loaded.

Figure 6.11: Effect of inclusion of payload (2x1).

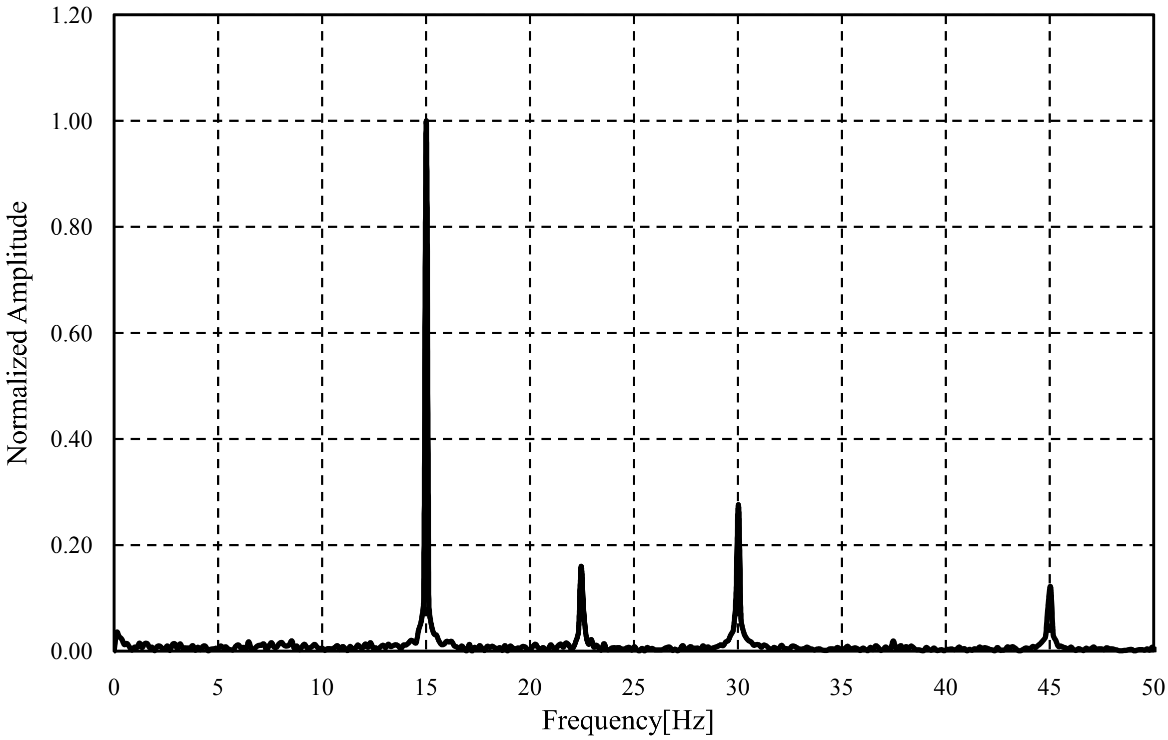


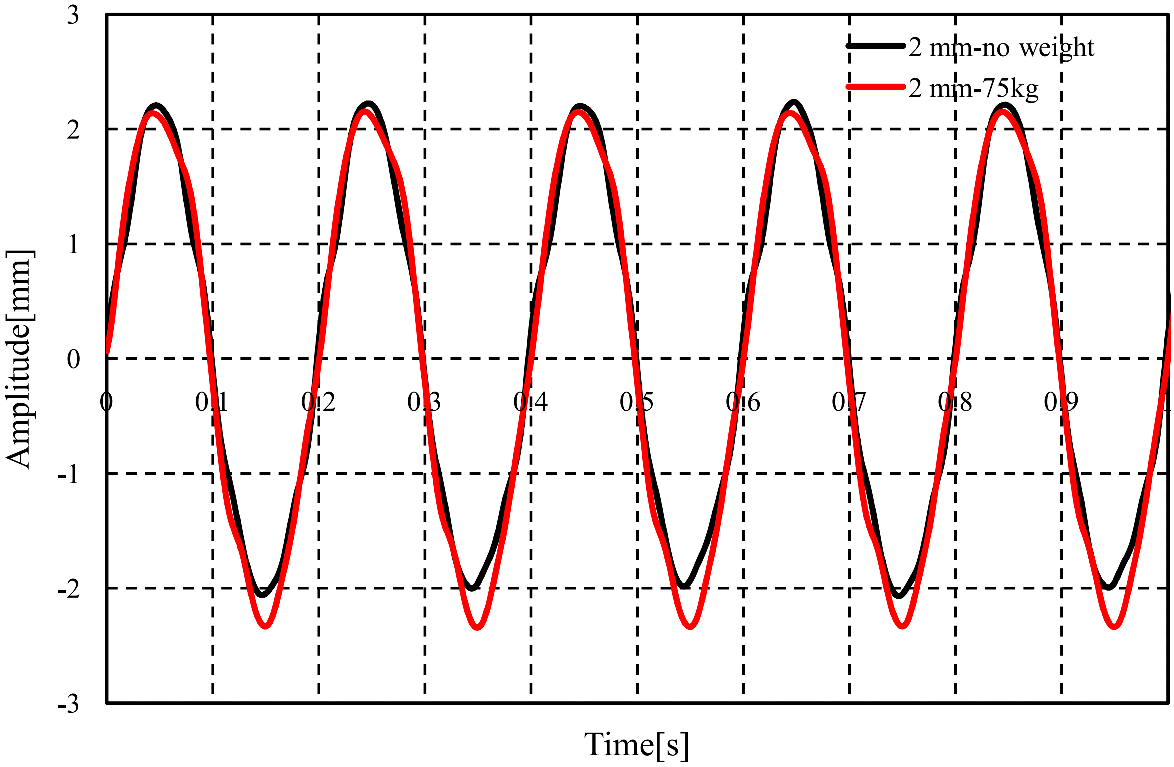
Figure 6.12: Fourier analysis of 15 Hz–loaded case (2x1).

useful in the context of the maritime transportation industry.

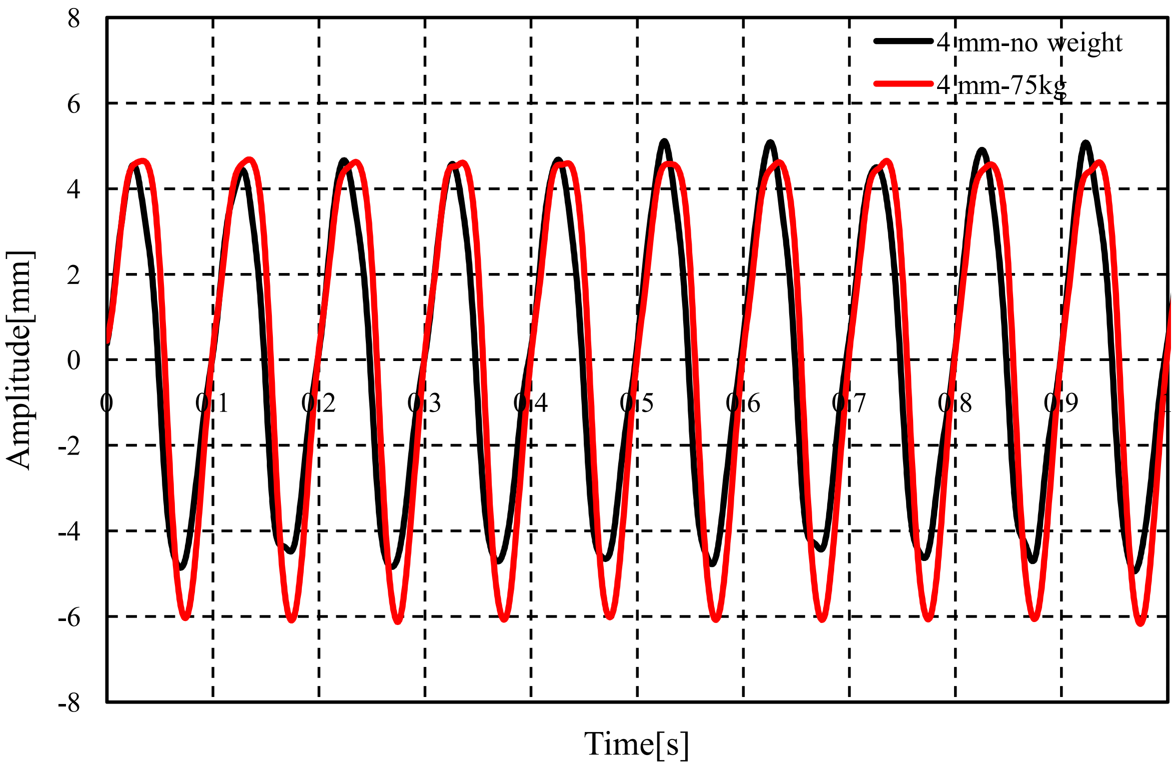
- Payload is a promising variable to be used in further studies. Payload distribution has a significant effect not only in the system response but in the ship's stability also. In this panorama, evaluation of the correlation of this variable and system response is strongly recommended.

- Gap size is a parameter that must be included in any further study because it was identified as the main source of non-linearity observed in the system response. Further research might investigate the effect of this variable in more realistic situations faced by containers during maritime transportation. An example would be arrangements of multi-stacks over 6 tiers, that are the most problematic panorama in the industry.

- Discrete approach for modeling the system's damping may not be the best approach. An alternative option must be taken into account.

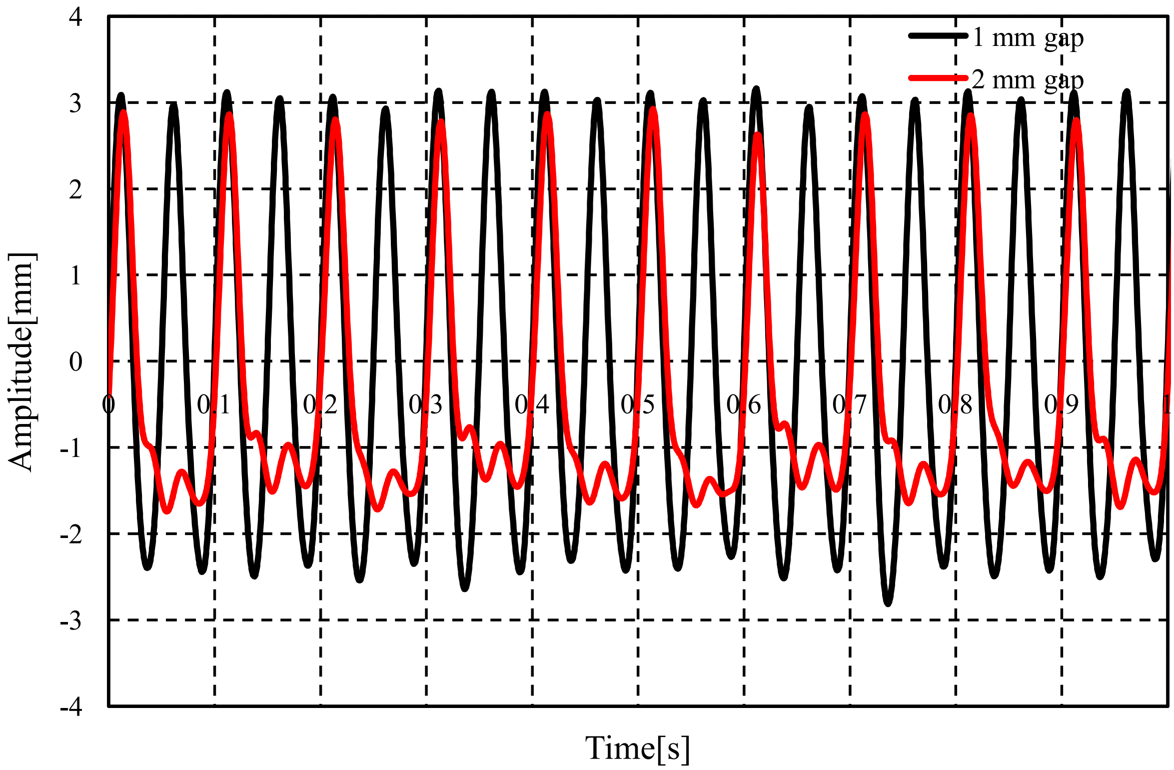


(a) Case: 2 mm–5 Hz–1 mm gap.

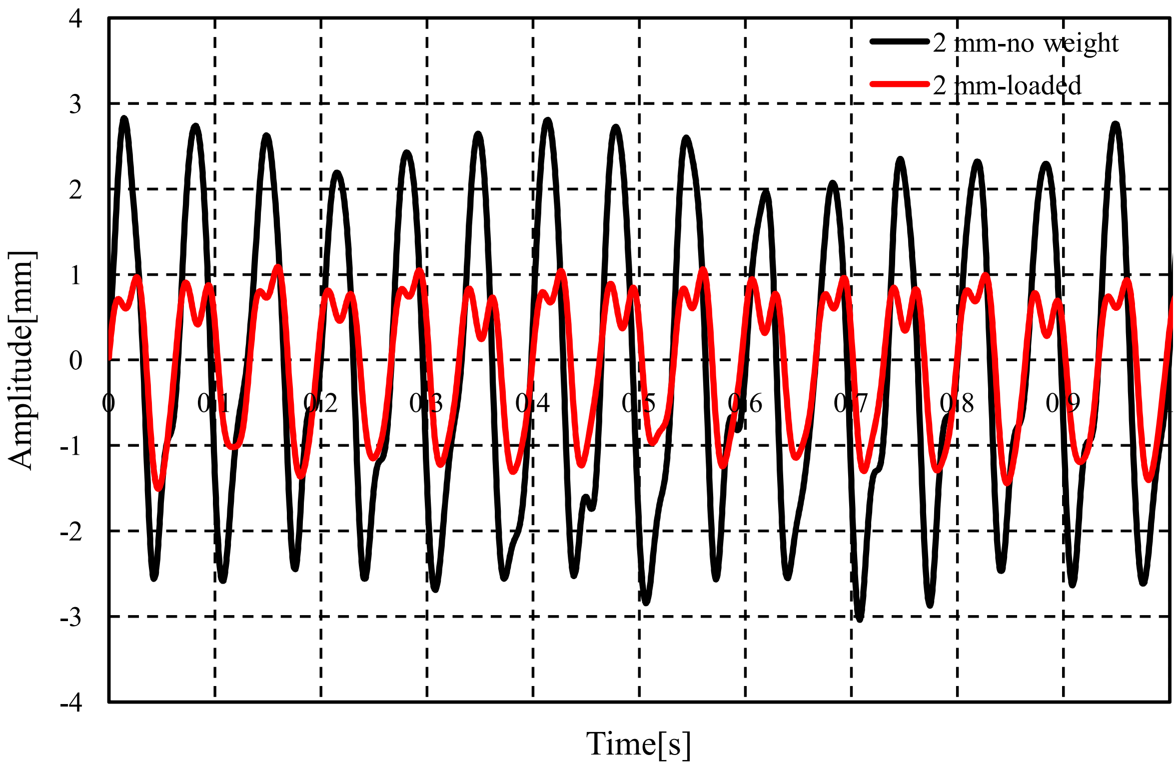


(b) Case: 4 mm–10 Hz–1 mm gap.

Figure 6.13: Load effect on response (2x1).



(a) Load effect for the non-linear cases.



(b) Effect of increase of gap size on the response.

Figure 6.14: Some other effects on response (2x1).